

## COMMENT ON “MEASURING THE BLACK HOLE MASSES OF HIGH REDSHIFT QUASARS”

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## ABSTRACT

In a recent paper, McLure & Jarvis (2002, astro-ph/0204473, v.1) reanalyze AGN broad-line reverberation measurements presented in Kaspi et al. (2000). They find the broad-line region size and the AGN luminosity at 5100 Å can be related by  $R_{BLR} \propto L_{5100}^{0.5}$ . This differs from the result of Kaspi et al., who found  $R_{BLR} \propto L_{5100}^{0.7}$ , a departure from expectations for a constant ionization parameter. In this note I investigate the source of the discrepancy. McLure & Jarvis use quasar luminosities based on the single-epoch, multichannel-spectrophotometer measurements of Neugebauer et al. (1987), obtained in 1980. I show that the Neugebauer et al. fluxes are systematically higher, by a constant flux offset, compared with the multi-epoch CCD measurements of Kaspi et al., obtained concurrently with the echo-mapping radii. In addition, McLure & Jarvis erred when converting these fluxes to luminosities. The two effects compound to a typical factor 2 (0.3 dex) overestimate of the luminosities of the PG quasars in the sample. Since McLure & Jarvis did adopt the Seyfert luminosities in Kaspi et al. (2000), they obtained a slope that is flatter by 0.2.

## 1. INTRODUCTION

Reverberation mapping of active galactic nuclei (AGNs) exploits the light-travel-time delay between continuum variations and the response of broad emission lines to measure the sizes of AGN broad-line regions (BLRs). This size can then be used, together with the estimated velocities of the BLR gas to derive masses for the central black holes (See Netzer & Peterson 1996, for a review.) The size-luminosity and mass luminosity relations of AGNs may shed new light on understanding these objects and the connections between the black holes in AGNs and those found in normal nearby galaxies.

Kaspi et al. (2000) measured reverberation sizes,  $R_{BLR}$ , for 17 PG quasars between 1991–1998 using the Wise Observatory 1m telescope and the Steward Observatory 2.3m telescope, with a combination of CCD spectrophotometry and photometry. The time averaged flux for each quasar was derived from 20–70 epochs per quasar. The rest-frame 5100 Å continuum flux densities were measured from the  $\sim 10$  Å resolution spectra while minding potential systematics such as broad-emission-line wings and atmospheric absorptions in the higher-redshift objects. Following Galactic extinction corrections (small for most of the objects) the absolute fluxes were used to calculate 5100 Å luminosities,  $\lambda L_{\lambda}(5100)$ . The sizes and luminosities of Seyfert galaxies with reverberation measurements were compiled from previously published works. A regression analysis taking into account the errors in both  $R_{BLR}$  and  $\lambda L_{\lambda}(5100)$  showed that  $R_{BLR} \propto [\lambda L_{\lambda}(5100)]^{0.70 \pm 0.03}$ . This was a surprising result, since it has long been speculated that the dependence would be to the power 0.5. Such a scaling would lead to an ionization parameter (ratio of ionizing photon density to electron density) at the surface of the BLR clouds that is independent of luminosity, and would explain the similarity of AGN spectra over many orders of magnitude in luminosity.

In a recent paper, McLure & Jarvis (2002) examine to what degree UV observables, namely 3000 Å luminosities and Mg II line velocities, can serve the purpose of the optical observables – 5100 Å luminosities and H $\beta$  widths – used to date in AGN black hole estimates. In the course of their work, they re-analyze the data presented by Kaspi et al. (2000) and conclude

that actually  $R_{BLR} \propto [\lambda L_{\lambda}(5100)]^{0.50 \pm 0.02}$  is the best fit, contrary to the result of Kaspi et al., and consistent with the expectations for a constant ionization parameter.

Vestergaard (2002) has carried out an analysis along similar lines. After studying the various systematics that can affect the slope determination, she concludes that the best estimate (her equation A5) is  $R_{BLR} \propto [\lambda L_{\lambda}(5100)]^{0.66 \pm 0.09}$ , consistent with the result of Kaspi et al. (2000). The statement by McLure & Jarvis (2002), that Vestergaard (2002) found a slope consistent with 0.5 but decided to adopt a slope of 0.7 anyway, is incorrect.

In this Note, I investigate the source of the discrepancy between Kaspi et al. and McLure & Jarvis. I show that it arises, first, due to the adoption by McLure & Jarvis of old, single-epoch, and systematically higher fluxes, but only for the high luminosity part of the sample; and second, due to incorrect conversion from flux to luminosity. This is confirmed and corrected in a revised version of their paper (R. McLure, private communication).

## 2. ANALYSIS

McLure & Jarvis chose to base their luminosities for the PG quasars in the Kaspi et al. (2000) sample on the measurements by Neugebauer et al. (1987). These measurements were obtained in 1980 with a multichannel spectrophotometer mounted on the Palomar 5m telescope. The measurements had coarse resolution of  $\sim 300$  Å, making the avoidance of emission and absorption lines in the measurement more difficult. In the numbers tabulated by Neugebauer et al., interpolation is needed, for most of the quasars, to obtain the flux at rest wavelength 5100 Å. As opposed to the measurements of Kaspi et al. (2000), only one epoch per object exists, inducing scatter due to the time variability of quasars. More importantly, the Neugebauer et al. (1987) measurements were obtained about 20 years before the Kaspi et al. (2000) size measurements, and it has been shown in Seyfert galaxies that BLR size and emission-line width change with time in individual objects (Peterson & Wandel 2000).

Figure 1 compares the observer-frame quasar flux densities measured at wavelengths corresponding to rest-wavelength 5100 Å, as reported by Kaspi et al. (2000), to the correspond-

ing numbers obtained from Neugebauer et al. (1987), after the necessary interpolation and conversion to  $f_\lambda$  in the latter dataset. Apart from the large differences in a few objects, presumably due to variability, there is a clear additive systematic offset between the datasets, in the sense that the Neugebauer et al. (1987) measurements have higher flux. While one cannot say for sure which dataset is at fault, it is possible that the Palomar data suffer from imperfect sky subtraction – a task that is much easier with present-day two-dimensional CCD detectors. To get a “third opinion” I have compared the Kaspi et al. (2000) flux densities to those indicated by the data of Boroson & Green (1992). The Boroson & Green (1992) fluxes are generally *lower* than the Kaspi et al. fluxes by about 30%. This difference is reasonable, given that they were obtained through a narrow 1.5'' slit, and at non-parallactic angles, and hence some light loss is expected.

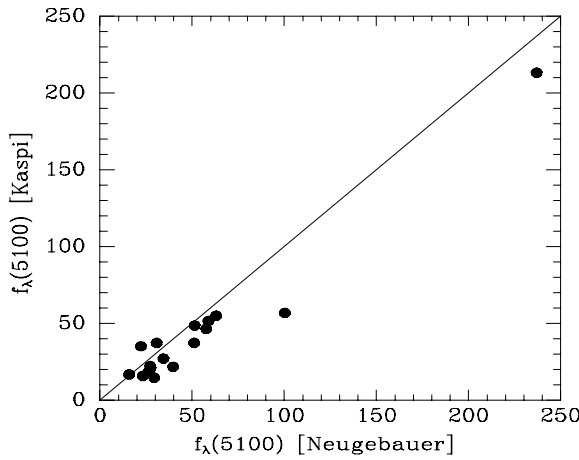


Fig. 1– Comparison of  $f_\lambda[5100(1+z)]$  flux densities for PG quasars measured by Kaspi et al. (2000) and by Neugebauer et al. (1987). Units are  $10^{-16} \text{ erg s}^{-1} \text{ cm}^{-2} \text{ \AA}^{-1}$ .

Fig. 2– Comparison of luminosities  $\lambda L_\lambda$  at rest wavelength 5100 Å, calculated from each of the datasets in Fig. 1.

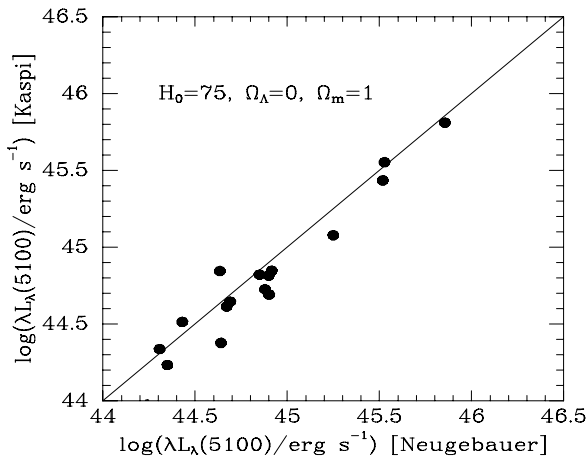


Figure 2 examines the effect of this flux discrepancy on the calculated luminosities. It compares the 5100 Å luminosities I have calculated from the Neugebauer et al. (1987) fluxes to the luminosities found by Kaspi et al. (2000). In both cases, the cosmology assumed is  $H_0 = 75$ ,  $\Omega_m = 1$ , and  $\Omega_\Lambda = 0$ . As expected, the lower luminosity quasars are most affected, and their luminosities are about 0.1 dex higher when based on the Neugebauer et al. (1987) numbers. This conclusion was also reached by Vestergaard (2002), and Figure 2 is nearly identical to her Figure 2a. Indeed, comparing directly her and my numbers for the luminosities calculated from the Neugebauer et al. data, I find only small differences of order 5%, which are ascribable to the interpolation of the Neugebauer et al. data.

In Figure 3, I compare the quasar luminosities listed by McLure & Jarvis, to my own calculation based on the same Neugebauer et al. data, assuming the cosmology cited by McLure & Jarvis,  $H_0 = 70$ ,  $\Omega_m = 0.3$ , and  $\Omega_\Lambda = 0.7$ . Specifically, I calculate

$$L_\lambda(5100) = 4\pi d_L^2(1+z)f_\lambda[5100(1+z)],$$

where, for the flat ( $\Omega_{total} = 1$ ) cosmologies we consider here, the luminosity distance is

$$d_L = cH_0^{-1}(1+z) \int_0^z [\Omega_m(1+z)^3 + \Omega_\Lambda]^{-0.5} dz.$$

Figure 3 indicates that there is an error in McLure & Jarvis’s conversion to luminosities, resulting in too-high luminosities by about 0.2 dex, especially at the higher luminosities. R. McLure (private communication) confirms that this is a programming error that resulted in an extra factor  $(1+z)^2$ .

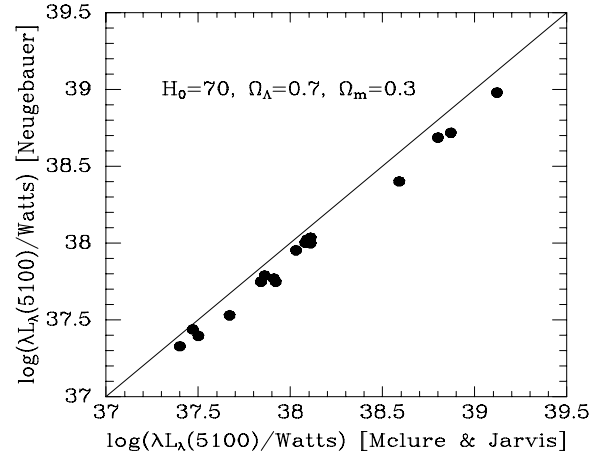


Fig. 3– Comparison of 5100 Å luminosities reported by McLure & Jarvis (2002) with luminosities calculated here from the same Neugebauer et al. (1987) data they used, and for the same cosmology.

Finally, in Figure 4, I compare the quasar luminosities listed by McLure & Jarvis, to the luminosities of Kaspi et al. (2000), after converting the latter to the cosmology and units used by the former. Here one sees the compound effect of the higher fluxes and the incorrect conversion to luminosity used by McLure & Jarvis. This leads to a total offset of about 0.3 dex (a factor 2).

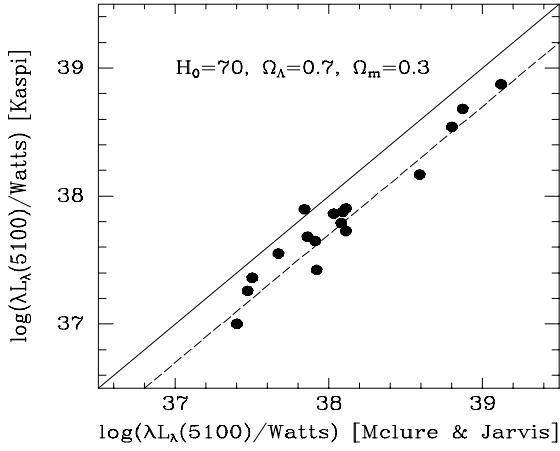


Fig. 4— Comparison of the Kaspi et al. (2000) luminosities and the McLure & Jarvis (2002) luminosities, after converting the former to the cosmological model and units used by the latter.

The systematically higher, by 0.3 dex, quasar luminosities used by McLure & Jarvis, can explain the flatter slope they obtained in the  $R_{BLR}$  vs  $L_{\lambda}(5100)$  relation. While preferring the Neugebauer et al. measurements over those of Kaspi et al. for the quasars, McLure & Jarvis adopted the Seyfert luminosities as given in Kaspi et al. (2000). Since the Seyfert  $R_{BLR}$  and  $L_{\lambda}(5100)$  values are, respectively, about 0.8 dex and 1.15 dex lower than those of the quasars, increasing the quasar luminosities by 0.3 dex, will lower the slope of the relation from 0.7 to 0.55. Some additional flattening also arises from the use of the  $\Omega_{\Lambda}$ -dominated cosmology, which makes the higher-redshift quasars in the sample slightly more luminous. In a revised version of their paper (R. McLure private communication), McLure & Jarvis find a best-fit slope of 0.6 when using the Neugebauer et al. (1987) data, and  $0.65 \pm 0.11$  when using the Kaspi et al. fluxes, fully consistent with Kaspi et al. (2000) and Vestergaard (2002).

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